

AIR BUBBLE FORMATION PROCESS OBSERVED IN THE G6 ANTARCTIC ICE CORE

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Abstract: Air bubble formation processes were investigated on a 100 m-long ice core from G6, Antarctica (73°07'S, 39°46'E). The observational results revealed clearly the five-stage process of air bubble entrapment. The pore space was closed off at a depth of 72 m, which leads to about 470 years age difference between air bubbles and the ice estimated under an assumption of 9 cm of ice/year for the accumulation rate.

1. Introduction

Polar glacier ice contains past atmospheric gases in small air bubbles formed during the transformation of firn to glacier ice. The pore close-off depth varies from one site to another on the ice sheets, depending on the firnification process influenced by temperature and accumulation rate. To investigate fully the air bubble chronology, detailed measurements are required on the bubble entrapment processes in the ice sheets.

Optical microscopic observations were made to study pore/bubble characteristics of ice core samples from G6, Antarctica (73°07'S, 39°46'E). The G6 core was drilled down to a depth of 99.85 m by the 27th Japanese Antarctic Research Expedition in 1986. The elevation of G6 is 3005 m a. s. l. (NISHIO *et al.*, 1986) and the 10 m snow temperature is -43.1°C (Antarctica: East Queen Maud Land, Enderby Land Glaciological Folio, Sheet 7, Tokyo, National Institute of Polar Research, 1989).

2. Experimental Procedures

Vertical thin sections were prepared to measure air bubble size, volume, shape and concentration with 5 to 20 m depth intervals. Vertical sections were first bandsaw-cut from ice core samples, attached to glass-plates and then surface-microtomed to thickness less than 3 mm for microscopic observations. The length and width of each section are about 7 and 4 cm respectively.

Circular approximation was made to measure air bubble size on an equal-area basis on the 2-D air bubble image. For air bubble volume calculations, spherical or ellipsoidal approximation was made for the 3-D bubble shape. When a bubble was made of several segments, each segment was taken as an ellipsoid and the ellipsoidal volumes were added up to calculate the bubble volume. Segment number was defined

to examine the bubble shape as the number of segment ellipsoids for each bubble. When a bubble is observed to be spherical (circular image under a microscope), the segment number is zero.

Sample preparations and microscopic observations were conducted in a cold room laboratory (-10°C).

3. Experimental Results and Discussions

All experimental results are summarized and shown in Fig. 1. The porosity values were calculated from bubble volumes. The air bubble formation process observed in the G6 core (Fig. 2) might be divided into five stages with depth as follows:

Stage 1: 0.5–47 m depth ($\rho=380\text{--}720\text{ kg/m}^3$): Pre-existing bubbles

Snow/firn contains small spherical bubbles of size about 0.1 mm (Fig. 1e), and the bubble concentration is about $50/\text{cm}^3$ (Fig. 1c). These bubbles might have formed during snow crystal growth in the atmosphere (SCHWANDER, 1989) and/or the sintering of snow grains at the ice sheet surface in addition to the bubble entrapment in thin ice crust layers (Fig. 3).

Stage 2: 47–62 m depth ($\rho=720\text{--}780\text{ kg/m}^3$): Onset of bubble formation

Channel networks of pore space are formed and total bubble volume in the ice

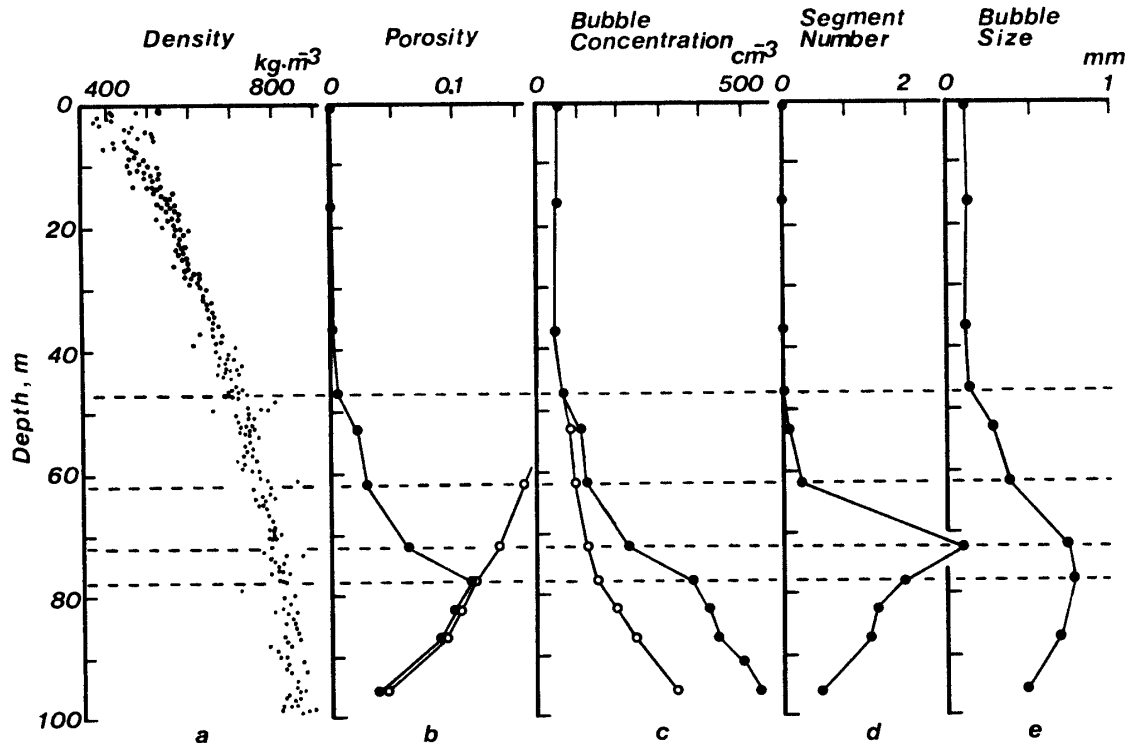


Fig. 1. Summary of the results obtained. (a) Bulk density (SHOJI and FUJII, 1991), (b) Porosity: Open circles show values calculated from the bulk density profile; solid circles show part attributable to air bubble volume, (c) Bubble concentration: Solid circles show total bubble concentration; open circles show the spherical bubble concentration, (d) Segment number, (e) Bubble size.

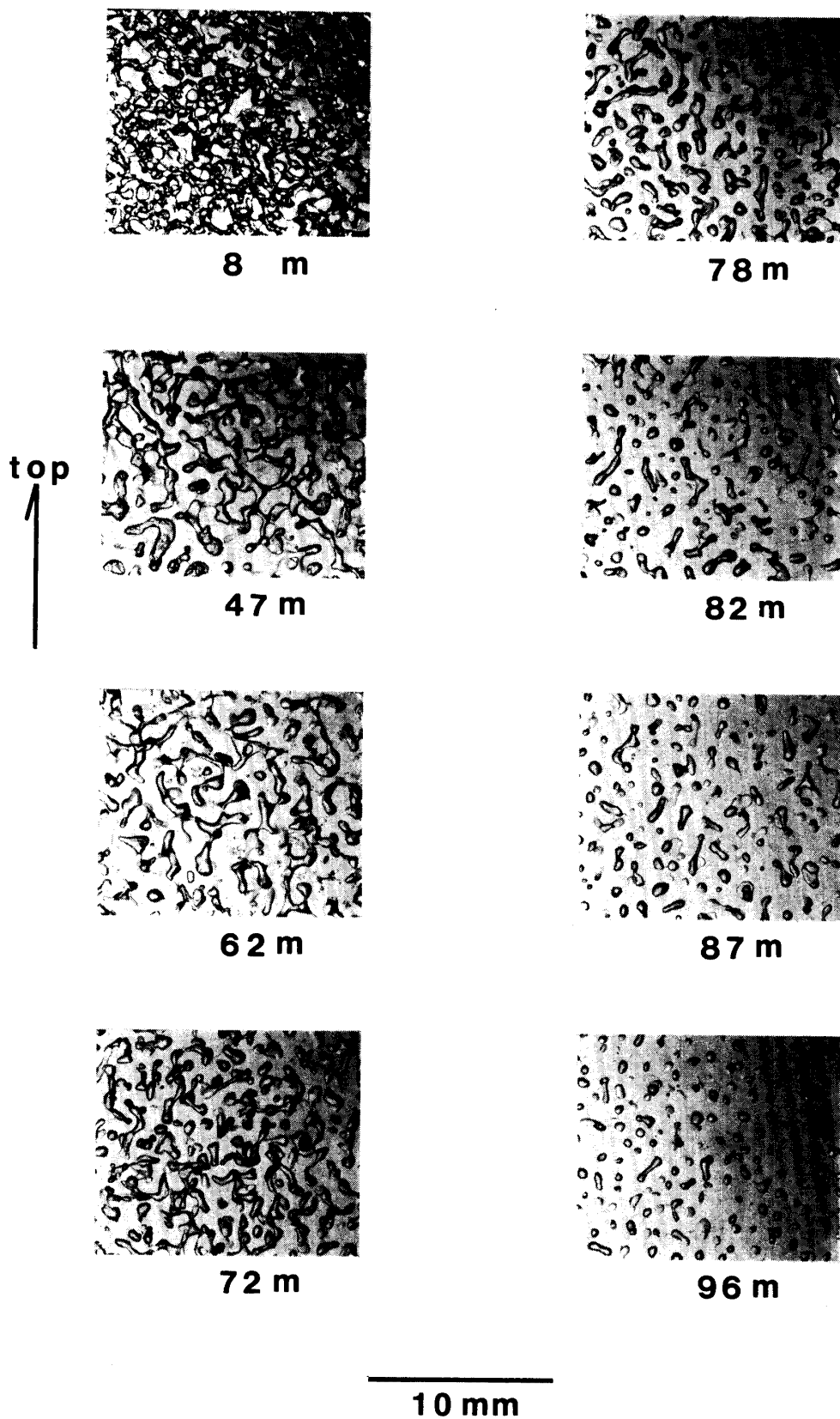


Fig. 2. Air bubble formation process observed in the G6 ice core.



Fig. 3. Air bubbles observed in an ice crust layer at a depth of 46.9 m.

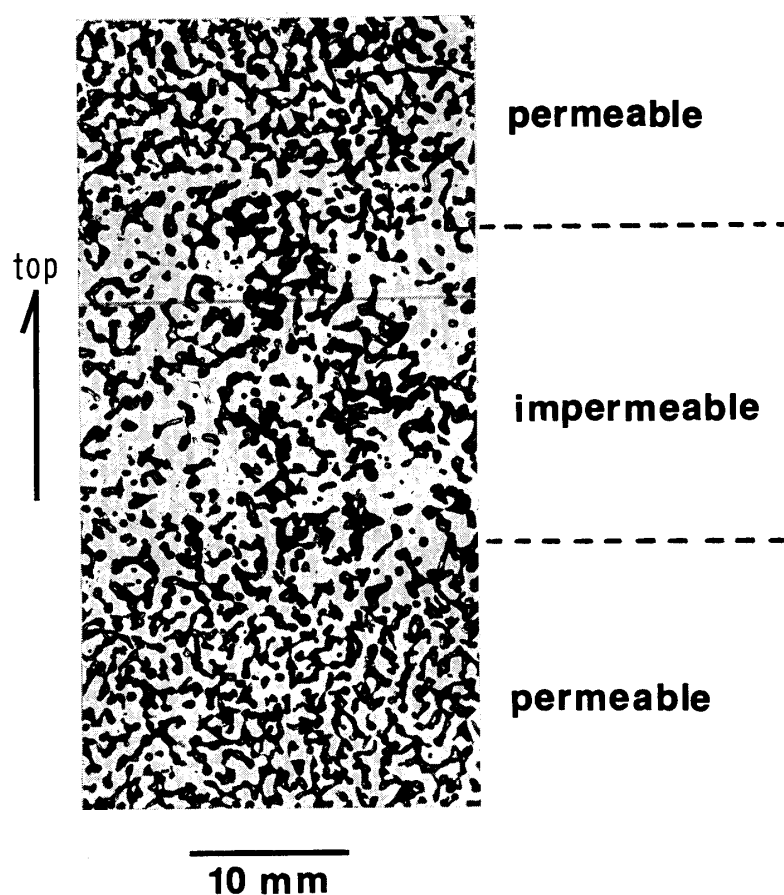


Fig. 4. Alternate layering of permeable and impermeable parts observed at a depth of 72.2 m.

starts to increase (Fig. 1b) due to the onset of air channel close-off.

Stage 3: 62–72 m depth ($\rho=780\text{--}810\text{ kg/m}^3$): Enhanced bubble formation

Bubble formation takes place quite actively (Fig. 1b, c). The scattered closing-off of air channels produces relatively large and irregularly shaped bubbles, as can be seen in the rapid increases in segment number and bubble size (Fig. 1d, e). Vertical discontinuity in channel closing can also be seen as the alternating permeable/impermeable layering structure shown in Fig. 4.

Stage 4: 72–78 m depth ($\rho=810\text{--}820\text{ kg/m}^3$): Completion of pore closing-off

Bubble concentration increases (Fig. 1c) due to the separation of smaller, spherical

bubbles from larger, irregularly shaped bubbles, although the channel closing is still active (Fig. 1b). This results in a decrease in segment number (Fig. 1d). At a depth of 78 m, all air channels are closed off, as seen in the matching between pore space and total bubble volume (Fig. 1b).

Stage 5: below 78 m depth ($\rho > 820 \text{ kg/m}^3$): Bubble multiplication and compaction

Separations of small spherical bubbles are still going on from larger bubbles as seen in the increase in bubble concentration and the decrease in segment number (Fig. 1c, e). Further densification of the ice occurs only through the compaction of air bubbles.

4. Pore Close-off Depth

Air bubble formation in the G6 ice core was completed at a depth of 78 m, as seen in the former section. The pore close-off depth where half of the pore space is attributed to the air bubble volume (SCHWANDER and STAUFFER, 1984) is a measure of the chronological difference between air bubbles and ice matrix; it was measured to be 72 m at G6 (Fig. 2). The age of ice at 72 m is about 470 a B. P. if we assume an accumulation rate of 9 cm of ice/year at G6 (SHOJI *et al.*, 1992). This means that the age of air bubbles is about 470 years younger than that of the ice surrounding them. These findings are important for further investigation of environmental changes by gas analysis of the G6 ice core.

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